NOAA Technical Memorandum OAR GMD-17

AN OVERVIEW OF HARDWARE AND SOFTWARE MODIFICATIONS TO IMPROVE THE EPPLEY SMT-3 SOLAR TRACKERS

A. Jordan
E. Hall
J. Wendell
E. Dutton

Earth System Research Laboratory
Global Systems Division
Boulder, Colorado
August 2012

noaa NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION / Office of Oceanic and Atmospheric Research

NOAA Technical Memorandum OAR GMD-17

AN OVERVIEW OF HARDWARE AND SOFTWARE MODIFICATIONS TO IMPROVE THE EPPLEY SMT-3 SOLAR TRACKERS

A.Jordan
E. Hall
J. Wendell
E. Dutton

Earth System Research Laboratory
Global Monitoring Division
Boulder, Colorado
August 2012

UNITED STATES
DEPARTMENT OF COMMERCE

Dr. Rebecca M. Blank
Acting Secretary

NATIONAL OCEANIC AND
ATMOSPHERIC ADMINISTRATION

Dr. Jane Lubchenco
Under Secretary for Oceans
and Atmosphere/Administrator

Office of Oceanic and
Atmospheric Research

Dr. Robert Detrick
Acting Assistant Administrator

For sale by the National Technical Information Service, 5285 Port Royal Road
Springfield, VA 22161

An Overview of Hardware and Software Modifications to Improve the Eppley SMT-3 Solar Trackers

Allen Jordan, Emiel Hall, Jim Wendell, Ellsworth Dutton

Version 1.02, December 2, 2011

Introduction

The NOAA ESRL/GMD Solar Radiation group has long relied on sun trackers to make routine measurements of solar irradiance with pyrheliometer and pyranometer instruments. This requires accurate positioning of the instruments as the sun moves through the day over each monitoring station. Unfortunately, most of the Eppley solar trackers NOAA purchased in the late 1980s had fallen into disrepair and shown problems with internal cable windup and load-bearing ability, so they were no longer being used. However, they do provide a mechanically sound core for a tracking system. This document lists the steps taken to improve the hardware (mechanical and electrical) and software while reconditioning these old trackers.

Mechanical Changes

The first step in refurbishing and upgrading an Eppley solar tracker is completely disassembling it. Unless the tracker is in a nearly new physical condition, all bearings, seals, o-rings, and screws/washers should be removed and discarded as necessary. The first modifications involve the elevation and azimuth worm gear assemblies. All threaded holes are re-tapped to remove any corrosion and residue, and new bearings are inserted. The lower screw slots are often too small to allow the full desired range of movement when engaging/disengaging the main gears, so they are milled approximately 0.1” longer in each direction with a ¼” diameter endmill (see Figure 1). The rear holes are wiped clean through the back side if they haven’t been already.

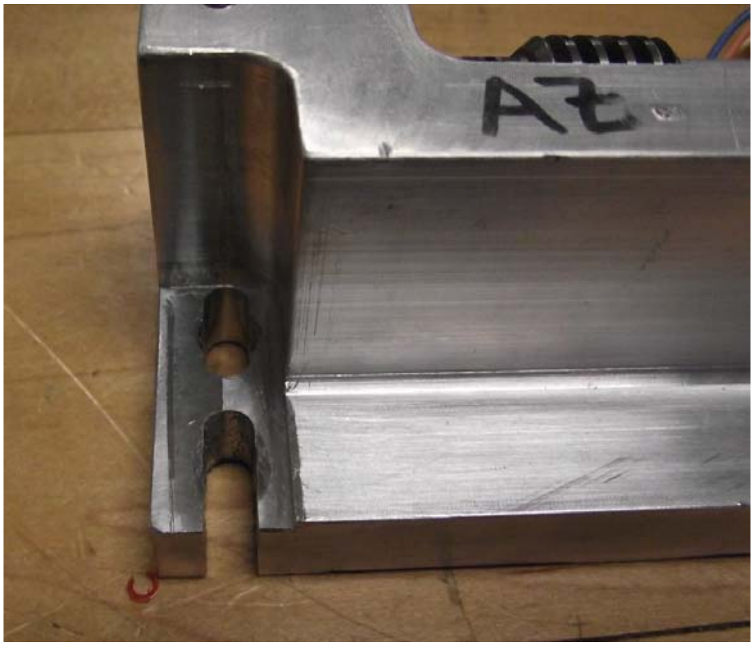

Figure 1: Slots in the worm-gear assembly. These are milled longer, along with the slots on the opposite side.

The existing stepper motors are removed from the worm-gear assemblies and replaced with higher-power motors (103H7123-5740, 2A, 1.15 oz-in). The new motor on the azimuth assembly is a little too large to fit into the tracker base, so the back corner opposite to the wires is wiped off on the mill to create extra clearance (see Figure 2).

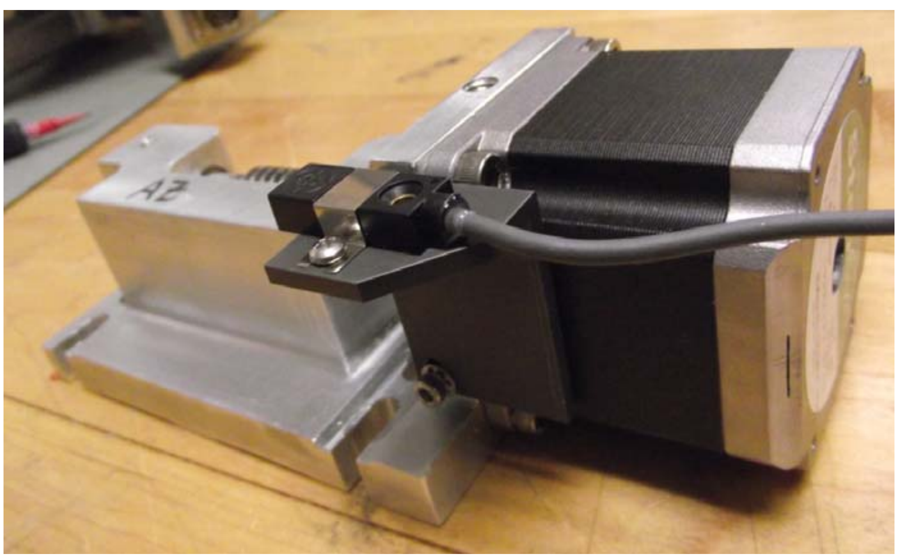

Figure 2: Wiped edge of the azimuth motor, and hall-effect sensor attachment.

Next, brackets for hall-effect sensors are installed, along with the sensors themselves (Figure 2). These sensors allow zeroing to a "home" position periodically to have a reference position and check for missing motor steps when resetting the tracker. They also allow for counting the number of azimuth rotations/windups, enabling the software to force a rewind if the internal wiring gets wrapped up beyond two rotations in either direction. The bracket is an L-shaped piece of aluminum with a few slots for adjusting the vertical mounting position, and tapped holes for attaching the sensor. One corner is wiped to allow clearance for the azimuth mounting, just like the motor.

Some additional machining is required on the bearing cups and elevation stop rod. After removing the old bearings, the cups are chucked into a lathe and a small bit of metal is removed where the inner race of the bearings could rub, giving enough clearance to allow smooth rotation. The new bearings and seals are press-fit into the modified cups afterwards. Next the metal cap is removed from the elevation stop rod to make room for the hall-effect sensor, which usually requires a torch to melt the locking compound and/or solder that holds it in place. The rod is then chucked in, and a small chamfer is turned down on the end to reduce any chance of the rod getting stuck if it collides with one of the tracker housing side walls in the event of an instrument failure (Figure 3).

Figure 3: Chamfer on the elevation stop rod.

A bracket to mount a wire terminal strip is then attached in the upper tracker housing. It has two countersunk holes for flathead screws attaching it to the tracker case, and several tapped holes for the terminal mounting (Figure 4). The terminal strip attaches as shown in Figure 5, with a tie-down to keep the wiring contained.

Figure 4: Terminal strip bracket.

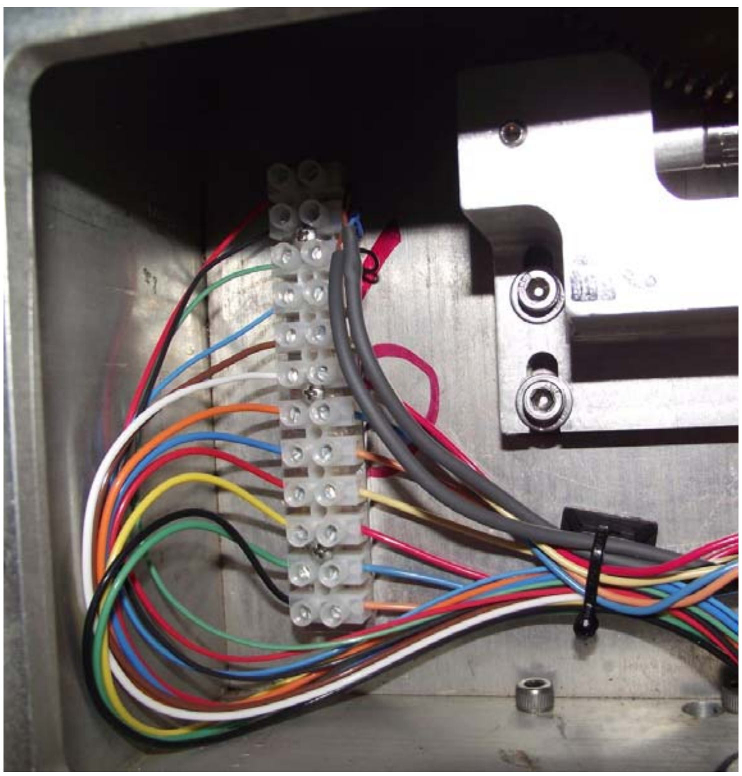

Figure 5: Terminal strip.

A new connector is wired to the terminal strip that matches the cabling to the controller electronics box, and unneeded holes are plugged (Figure 6). Finally, the tracker is completely reassembled, using new screws and washers with an anti-seize lubricant.

Figure 6: New connector and plugs.

Electronics Changes

A new controller electronics box is built for each reconditioned sun tracker. It contains a power supply, microcontroller board, stepper motor drivers, GPS, battery backup for the clock, “joystick” buttons for finely adjusting azimuth/elevation positions, and an optional heater (Figure 7).

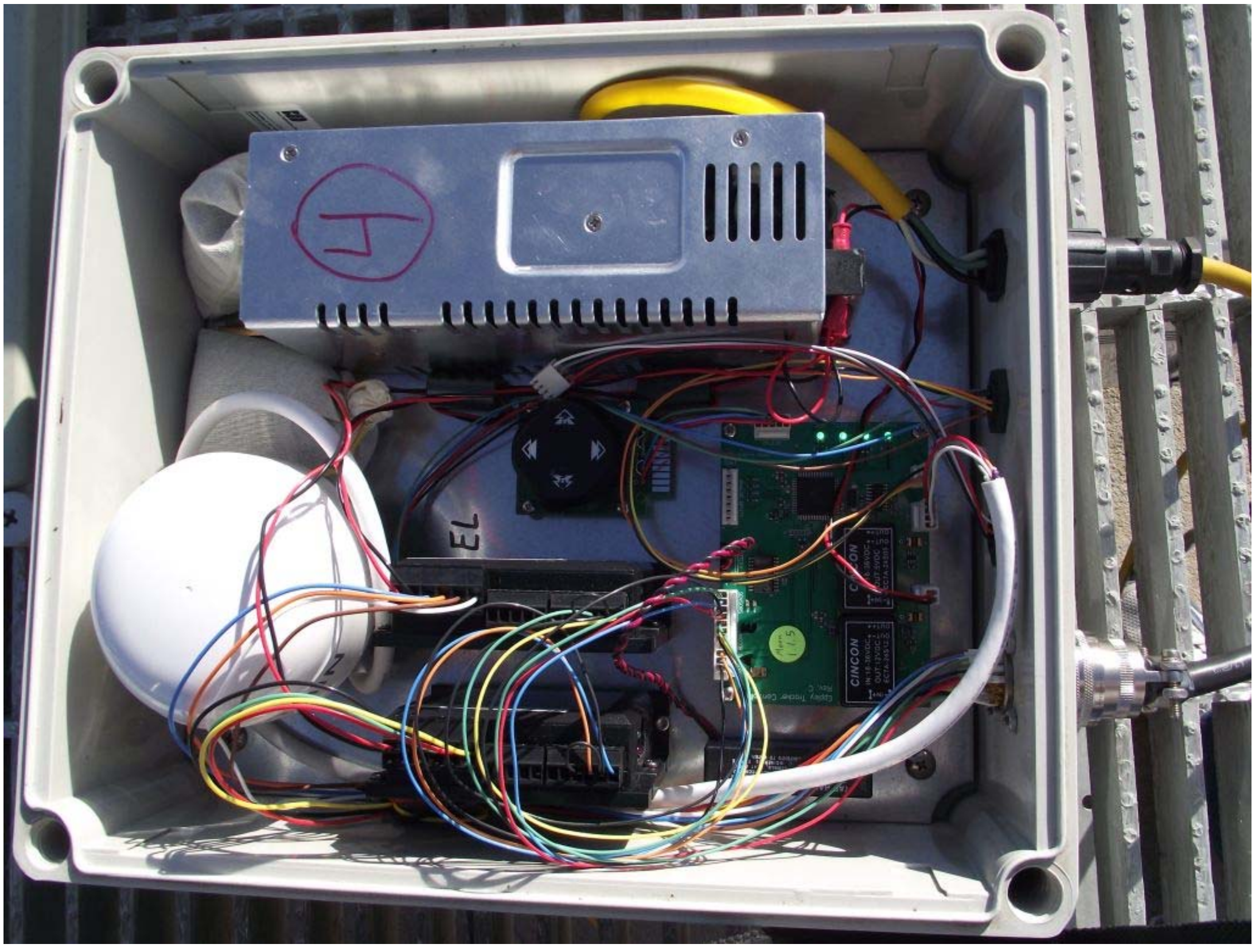

Figure 7: Controller electronics box.

The Garmin GPS is added for automatic position acquisition when a tracker is setup on-site. The stepper-motor drivers are capable of very high stepping resolutions (25600 steps/rev is used, with the 96:1 gearing ratio of the trackers, to get 2457600 steps/rev of the azimuth and elevation shafts), allowing for smooth, fine-grained tracking ability. The microcontroller board has an Atmel ATmega64 as the main controller. It uses robust dc-dc converters as voltage sources to allow startup and operation even in very cold temperatures, and monitors the power to check for drops. A precise real-time clock (RTC) chip is included, with a large battery backup, to keep accurate time. It is periodically set to the GPS date/time by the controller to keep any long-term clock errors to a minimum. To allow user adjustments to the tracking, the joystick buttons are setup to apply tracker position adjustments in 0.1 degree increments to the elevation/azimuth positions.

Cables for the power and tracker housing connection are carefully sealed with outdoor connectors and potting compound to protect against the elements. Extra unused wires are run in the tracker cable to allow internal heating in the future if necessary (this will be important for

South Pole deployment). Most of the wiring internal to the tracker and electronics box is Teflon-insulated for durability.

Software Changes

All the tracking control is done on custom firmware written for the ATmega64 microcontroller board. The sun position is calculated using the NREL SOLPOS algorithm, which has an uncertainty of +/- 0.01 degrees and will work until the year 2050 (1). Future controller implementations might make use of a different algorithm to get past the 2050 date, preventing problems in the distant future. Latitude and longitude are read from the GPS, and date/time from the battery-backed RTC chip to feed into the sun position calculations. The azimuth and elevation hall-effect sensors are monitored for initial and periodic resets of the motors to the zeroing position to reduce accumulated errors from missing motor steps or other tracking inaccuracies. The number of azimuth rotations is monitored (there are sites where the sun will do multiple azimuth revolutions before setting), and a reset is forced if too many windings occur.

The firmware has several useful features aside from basic solar tracking. A terminal / serial port command-line menu interface is implemented to allow for various user settings. A “sleep” position can be set for pointing the tracker at night, which is useful for heat-lamp warming in cold climates, or other desired overnight parking positions. The tracker position offsets can be manually set, and to finer increments than the joystick buttons can provide. Various continuous rotation modes can also be set: azimuth-only for bubble level monitoring/adjusting, and both elevation/azimuth for initial gear wear-in. Finally, the date/time and latitude/longitude are user-settable for various testing setups, and the tracker can be set in “manual” mode for custom azimuth/elevation position movements.

An experimental moon tracking firmware has also been developed, making tracker implementations possible for lunar viewing instruments. Moon position is calculated using the Schlyter algorithm, which has an uncertainty of +/- 0.03 degrees (about 2 arc minutes) (2). It is also possible to combine sun and moon tracking; the sun is tracked during the day, allowing for position adjustments with the joystick buttons in bright sunlight to get the alignment correct, and the moon is tracked when the sun falls 5 degrees below the horizon. If both the sun and moon are down, the tracker moves to its sleep position.

Results and Deployment

NOAA-modified trackers are currently deployed at Boulder, Colorado; the Boulder Atmospheric Observatory tower near Erie, Colorado; the American Samoa GMD Baseline Observatory; and the Mauna Loa Observatory, Hawaii. The trackers are operating as intended, with high positioning accuracy (better than 1/10 degree). Solar aligned instrument data are successfully being retrieved from all sites with few operational issues. The trackers are designed to have a simple setup procedure and autonomous operation, with easy ways to test for instrument cable clearance, leveling, and tracking position adjustments.

Setting up a tracker starts with mounting it loosely to a solid flat surface with three bolts matching holes in the base of the tracker, pointing the cable end of the base close to north. The mounting surface should be rigid and not susceptible to any perceivable motion under all anticipated environmental conditions. By unplugging the internal GPS connector and holding a "joystick" button while powering up the tracker control box, the azimuth motor will rotate back and forth to allow visual level adjustment using the threaded leveling feet and attached bubble levels. The level should be maintained throughout the complete rotation about the vertical axis. Once level, the base is tightened down to prevent any unwanted movement (the nuts must be tightened evenly, and the leveling should be checked again after), and the tracker is reset by power cycling. A similar rotating procedure can be used after mounting the solar instruments to check cable clearance, preventing snags and wrapping. When ready to track, the GPS connector is reattached inside the box to automatically read location/time, and sun tracking will begin after acquiring a position lock and making initial calculations. Once the motors have moved into their tracking positions, the "joystick" buttons in the controller box are pressed repeatedly to slightly adjust the tracking position (0.1 degrees per press) until the sun is perfectly in line on the target instrument. Any additional solar instruments are mounted to align with the first instrument.

The trackers are designed to have a wide temperature tolerance for various environments, run safety checks preventing wire windup and other internal damage, and periodically reset to reduce propagated errors from mechanical inaccuracies. In cold environments, sleep positions can be set to point at heat lamps overnight, keeping the mechanics and instruments from freezing solid. They also log any errors internally for retrieval in the event of a failure, and show current status visually for easy operational checking.

There have been a few issues with on-site setup that are being addressed. If a direct beam solar instrument (pyrheliometer) is mounted too low on the tracker, it can collide with the base at high sun elevation angles and become stuck. The solution is checking the instrument mounting position during setup, and making careful instructions to be followed when installing trackers at remote sites. Certain environments are also very corrosive to metal, notably high humidity and salt spray from the ocean. To keep rust and other corrosion away, the trackers are carefully lubricated and waxed before shipment. Drains are installed on the bottom of the tracker body to keep water from collecting through capillary action, condensation, or seal failure, and bags of desiccant are inserted into the electronics controller box and may be changed as necessary. At many locations rust will eventually form regardless of preparation, but the trackers will last at least a few years before needing maintenance or replacement.

Conclusion

Overall, refurbishing older solar trackers and adding the new hardware and software improvements is a worthwhile process, creating robust platforms for solar instruments that will perform well and last for a long time at a fraction of the cost of new similar solar tracking systems. They are straightforward to setup, require little maintenance, and give accurate tracking results. The modification steps are not overly difficult, even when refurbishing particularly worn older trackers, and will provide solid mechanics and extra power for many years of extra service.

References

1. "SOLPOS Solar Position and Intensity." *National Renewable Energy Laboratory*. NREL, n.d. Web. 6 Jan 2012. <http://rredc.nrel.gov/solar/codesandalgorithms/solpos/>.

2. Schlyter, Paul. "How to compute planetary positions." *Paul Schlyters hemsida*. N.p., n.d. Web. 6 Jan 2012. <http://stjarnhimlen.se/comp/ppcomp.html>.